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IN THE U.S. PATENT AND TRADEMARK OFFICE

Applicant: Wieslaw J. SZAJNOWSKI

Appl. No.: 09/633,275 Group:

Filed: August 4, 2000 Examiner:

For: METHOD AND APPARATUS FOR GENERATING RANDOM SIGNALS

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Assistant Commissioner for Patents
Washington, DC 20231

October 3, 2000

Sir:

Under the provisions of 35 U.S.C. § 119 and 37 C.F.R. § 1.55(a), the applicant(s) hereby claim(s) the right of priority based on the following application(s):

Country	Application No.	Filed
GREAT BRITAIN	9918518.3	August 5, 1999

A certified copy of the above-noted application(s) is(are) attached hereto.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fee required under 37 C.F.R. §§ 1.16 or 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By
Michael K. Mutter, #29,680

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Attachment

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<u>I N F O R M A T I O N   S H E E T</u>

jc841 U.S. PTO 09/633275 08/04/00

Applicant: SZAJNOWSKI, Wieslaw J.

Application No.:

Filed: August 4, 2000

For: METHOD AND APPARATUS FOR GENERATING RANDOM SIGNALS

Priority Claimed:

COUNTRY	DATE	NUMBER
United Kingdom	08/05/99	9918518.3

Send Correspondence to: BIRCH, STEWART, KOLASCH & BIRCH, LLP
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Falls Church, Virginia 22040-0747
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The above information is submitted to advise the USPTO of all relevant facts in connection with the present application. A timely executed Declaration in accordance with 37 CFR 1.64 will follow.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

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5 AUG 1999

Statement of inventorship and of right to grant of a patent

1.	Your reference	J00041734GB
2.	Patent application number *(if you know it)*	**9918518.3**
3.	Full name of the or of each applicant	Mitsubishi Electric Information Technology Centre Europe B.V.
4.	Title of the invention	
5.	State how the applicant*(s)* derived the right from the inventor*(s)* to be granted a patent	By virtue of an agreement between Wieslaw Jerzy Szajnowski, Unisar Limited, a British company of 3, The Red House, West Road, Guildford, Surrey, GU1 2AR, and the applicant.
6.	How many, if any, additional Patents Forms 7/77 are attached to this form? *(see note (c))*	1 (one)
7.		I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent applications relates to. Signature [signature] Date 5 August, 1999 R.G.C JENKINS & CO.
8.	Name and daytime telephone number of person to contact in the United Kingdom	S. D. Burke - 0171-931-7141

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2. Patent application number *(The Patent Office will fill in this part)*	9918518.3	-5 AUG 1999
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Mitsubishi Electric Information Technoloby Centre Europe B.V. 20 Frederick Sanger Road The Surrey Research Park Guildford, Surrey GU2 5YD United Kingdom	
Patents ADP number *(if you know it)*	7542749001	
If the applicant is a corporate body, give the country/state of its incorporation		
4. Title of the invention	METHOD AND APPARATUS FOR GENERATING RANDOM SIGNALS	
5. Name of your agent *(if you have one)*	R.G.C. JENKINS & CO.	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	26 Caxton Street London SW1H ORJ	
Patents ADP number *(if you know it)*	950001	

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METHOD AND APPARATUS FOR GENERATING RANDOM SIGNALS

This invention relates to a method and apparatus for generating random signals, and particularly but not exclusively random binary waveforms.

Random binary waveforms with specific correlation properties are required for ranging and other applications, especially in radar systems. It is particularly desirable to provide random binary waveforms with maximum unpredictability, hence with low probability of intercept, and also resistant to intelligent jamming. Furthermore, such random binary waveforms are also useful for applications in multiuser environments where many similar or disparate systems operate in the same geographical region and those systems share, at least partly, the same wide frequency band.

The generation of binary waveforms with specified correlation properties is of considerable practical interest in the field of radar and communications. For example, in low probability of intercept (LPI) radar the phase of the coherent carrier is modulated by a pseudorandom binary waveform to spread the spectrum of the transmitted signal. In some applications, such as collision avoidance/obstacle detection, altimetry, autonomous navigation etc., many similar radar systems should be capable of operating in the same region and sharing the same wide frequency band. To avoid mutual interference, each system should use a distinct signal, preferably orthogonal to the signals employed by all other systems. Therefore, the successful use of coded-waveform radar in a multiuser environment depends on the availability of large families of waveforms, each with specified correlation properties and low cross correlation values.

An important class of synchronous binary waveforms can be obtained from suitably constructed binary sequences, such as pseudorandom binary sequences. However, when the number and type of systems (cooperating or uncooperating) sharing the same frequency band is unknown and often cannot even be predicted, it is not possible to assign a distinct binary sequence to each of them. It is also difficult to construct large sets of long pseudorandom sequences that provide a significant improvement over purely random sequences.

The above problems can be avoided, or at least alleviated, when asynchronous random binary waveforms are used. In dense signal environments asynchronous waveforms are known to be superior to synchronous ones as a result of the additional randomisation of the zero crossing time instants. Because purely random binary waveforms exhibit maximum unpredictability, they are less vulnerable to intercept and intelligent jamming.

One convenient and inexpensive method to generate a random binary waveform is based on level crossings of a random signal generated by a physical noise source. Fig. 1 shows an example of a generator of a random binary waveform. The generator comprises a physical noise source (PNS) and a zero-crossing detector (ZCD) which can be a comparator or a hard limiter. Fig. 2 shows a typical realization of a noise signal s(t) and a random binary waveform b(t) obtained from that noise signal and defined by zero crossings of that signal.

In radar and also other applications the shape of the correlation function of a binary waveform is of primary importance. The ideal correlation function would have the form of an impulse (Dirac delta) function. In practice, the correlation function of a 'good' binary waveform should attempt to

approximate in some way this ideal shape. Fig. 3 shows the shape of the correlation function $R_b(\tau)$ of a random binary waveform b(t) ideal for ranging applications.

In practice it is relatively easy to generate noise signals with a Gaussian distribution, e.g., by exploiting thermal noise. When an underlying noise signal s(t) has a Gaussian distribution, the correlation function $R_b(\tau)$ of a binary waveform b(t) obtained from zero crossings of the signal s(t) can be determined from Van Vleck's formula

$$R_b(\tau) = (2\pi) \arcsin[R_s(\tau)]$$

where $R_s(\tau)$ is the correlation function of the underlying noise signal s(t). Therefore, in order to obtain a narrow correlation function $R_b(\tau)$ of a random binary waveform b(t), the correlation function $R_s(\tau)$ of an underlying noise signal s(t) should also be narrow. Because the correlation function and the power spectral density of a random signal form a Fourier pair, a physical noise source utilized to generate a binary waveform with a narrow correlation function should produce a noise signal with an extremely wide frequency spectrum.

It is known that the correlation function of a random binary waveform, not necessarily obtained from a Gaussian noise signal, has a cusp at the origin and that this cusp is sharper when the average number, N_0, of zero crossings in unit time is larger. When an underlying noise signal s(t) has a Gaussian distribution, the average number, N_0, of zero crossings in unit time can be determined from Rice's formula:

$$N_0 = B_s/\pi$$

where B_s is the angular root-mean-square (rms) bandwidth (measured in radians per second) of signal s(t). Consequently, when a Gaussian noise signal s(t) is employed to generate a random binary waveform b(t), it is not possible to reduce the width of the correlation function $R_b(\tau)$ of the binary waveform by means other than the increase in the rms bandwidth B_s of the underlying noise signal s(t). Unfortunately, the generation of ultra wideband noise signals is very difficult in practice.

It would, accordingly, be desirable to provide an apparatus and method for the generation of a random binary waveform with an extremely narrow correlation function suitable for ranging and other applications.

It would also be desirable to provide an apparatus and method for the generation of a random binary waveform intended for application in multiuser environments.

It would be further desirable to provide an apparatus and method for the generation of a random binary waveform resistant to deliberate intelligent jamming.

It would additionally be desirable to provide an apparatus and method for the generation of a random binary waveform with low probability of intercept.

According to one aspect of the invention there is provided a method of generating a resultant signal containing events which occur at random intervals, the method comprising generating a plurality of preliminary signals each containing events occurring at random intervals and combining the preliminary signals. The combining is performed in such a way as to

preserve, at least substantially, the events therein. In the embodiments described below, the combining results in the interspersing of the events in the resultant signal.

Throughout the present specification, including the claims, except where the context indicates otherwise, the term "random" is intended to cover not only purely random, non-deterministically generated signals, but also pseudo-random, deterministic signals such as the output of a shift register arrangement provided with a feedback circuit as used in the prior art to generate pseudo-random binary signals, and chaotic signals. Preferably, however, at least one of the preliminary signals is purely random (non-deterministic), or possibly chaotic.

According to a further aspect of the invention, a method of generating a random signal comprises producing a plurality of preliminary signals of random amplitude which can be level-detected to generate a binary waveform with transitions at random intervals, and combining the signals either before or after level-detection in order to generate a resultant random binary output. The combining of the signals is performed in such a manner that the events represented by the transitions are, at least partly, preserved. The preliminary signals are, at least partly, uncorrelated.

Some of the signals or binary waveforms to be combined can be obtained from a single signal or a single binary waveform by utilizing a plurality of suitably time-delayed replicas of this signal or waveform. The time-delayed replicas should be, at least partly, uncorrelated with each other, and to this end the time delay used to form each replica preferably has a value which

corresponds to a substantially zero level of the correlation function of the original signal.

Arrangements embodying the invention will now be described by way of example with reference to the accompanying drawings, in which like reference symbols represent like integers, and in which:

Figure 1 shows an example of a system for generating a random binary waveform in accordance with the prior art;

Figure 2 shows a typical realization of a noise signal s(t) and a random binary waveform b(t) obtained from that noise signal and defined by zero-level crossings of that signal;

Figure 3 shows the shape of the correlation function $R_b(\tau)$ of a random binary waveform b(t) ideal for ranging applications;

Figures 4 to 6 are block diagrams of, respectively, first to third embodiments of a system according to the present invention;

Figure 7 is a block diagram of a specific example of the embodiment shown in Fig. 6;

Figure 8 shows the correlation function of a random binary waveform generated by the embodiment of Figure 7;

Figure 9 is a block diagram of yet another embodiment of a system according to the present invention;

Figure 10 is a block diagram of a specific example of the embodiment shown in Fig. 8;

Figure 11 is a block diagram of a further embodiment of the present invention; and

Figure 12 shows the correlation function of a random binary waveform generated by the embodiment of Figure 11.

Fig. 4 shows a system according to the present invention that comprises a plurality of wideband physical noise sources (PNS) followed by spectrum-shaping filters (SSF), a plurality of analogue multipliers (AM) or balanced modulators, and a single zero-crossing detector (ZCD) which can be a comparator or a hard limiter. A random binary waveform (RBM) is obtained at the output of the zero-crossing detector ZCD.

Preferably the physical noise source (PNS) is a Zener diode used as *per* se known in the prior art, which provides an output having a Gaussian voltage distribution.

Preferably the zero-crossing detector (ZCD) is a fast comparator with a zero threshold.

In operation, each physical noise source (PNS) produces a waveform similar to that shown at s(t) in Figure 2, the waveforms being uncorrelated. Each waveform is filtered by a respective spectrum-shaping filter (SSF) which may have an approximately Gaussian power transfer function $|H(\omega)|^2$ of the form:

$$|H(\omega)|^2 = \text{const} \exp(-\omega^2/2B_s^2)$$

where B_s is the angular rms bandwidth.

The advantage of such a characteristic is that the Fourier transform exhibits a monotonic decline to zero level, and thus exhibits no undershoot or ringing. Other types of transfer functions, preferably exhibiting similar advantages, could alternatively be used. It is possible to use filters with identical characteristics for the respective channels (noise sources), or if desired different characteristics could be selected, or indeed in some circumstances the filters could be omitted.

The outputs of the first two filters are multiplied by the first of the analog multipliers (AM), the output of which is multiplied by the output from the third filter (SSF) in the next analog multiplier (AM), etc. The output from the final analog multiplier (AM) is also a waveform generally similar to s(t) in Figure 2 except that there is a substantially greater number of zero-crossings. In effect, the number of zero-crossings is the sum of the number in each of the respective signals from the noise sources (PNS). This output signal is delivered to the zero-crossing detector (ZCD) to produce the random binary waveform B(t), similar to that shown in Figure 2 but again containing a substantially greater number of transitions.

As a result of this arrangement, assuming that there are n channels, the number of zero-crossings in unit time as compared with a single noise source is increased by a factor of n, thus producing a substantially sharper correlation function and therefore a signal which is substantially less subject to interference. The rms bandwidth, however, is increased by only $\sqrt{n}$.

Although increasing the number of channels also increases the sharpness of the correlation function, the extent of the improvement reduces with an

increase in the number of channels. By way of example, assume that each spectrum-shaping filter has an approximately Gaussian power transfer function $|H(\omega)|^2$ of the form:

$$| H(\omega)|^2 = \text{const} \exp(-\omega^2/2B_s^2)$$

where B_s is the angular rms bandwidth of the filter. The table below shows the reduction in the half-height width of the correlation function of a random binary waveform as a function of the number of combined channels.

Number of identical channels combined	Half-height width of the correlation function (normalised units)
1	1.00
2	0.56
3	0.39
4	0.30
5	0.25
6	0.21
7	0.18
8	0.16

In practical embodiments, it is likely that the optinum number of channels would be three or four, as the cost of increasing the number of channels is unlikely to justify the added improvement in the signal.

In the embodiments to be described below, similar considerations apply to the preferred nature of the physical noise sources (PNS), the spectrum-shaping filters (SSF) and the zero-crossing detector (ZCD), and to the number of channels.

Fig. 5 shows another system according to the present invention that comprises a single wideband physical noise source (PNS) followed by a spectrum-shaping filter (SSF), a plurality of analogue delay lines (DL), a plurality of analogue multipliers (AM) or balanced modulators, and a single zero-crossing detector (ZCD) which can be a comparator or a hard limiter. A random binary waveform (RMB) is obtained at the output of the zero-crossing detector (ZCD).

Figure 5 differs from the arrangement shown in Figure 4 by virtue of the fact that, instead of using independent noise sources (PNS), a single noise source (PNS) is used, the remainder of the preliminary noise signals being produced by time-delayed replicas of the original noise signal, the delays being produced by the analog delay lines (DL). In order to ensure that the noise signals delivered to the analog multipliers (AM) are substantially uncorrelated, each delay line imparts a sufficiently long delay; the delay is such that the correlation function of the signal produced is substantially zero at that delay point. The delays may be different from each other, and/or may vary with time.

Fig. 6 shows yet another system according to the present invention that comprises a plurality of physical noise sources (PNS), each followed by a spectrum-shaping filter (SSF) and a zero-crossing detector (ZCD). The binary waveforms obtained at the outputs of the zero-crossing detectors (ZCD) are then fed to a suitable multi-input-single-output combiner (MIC) that processes those waveforms in such a manner that their respective zero crossings are, at least partly, preserved. A random binary waveform (RBM) is obtained at the output of the combiner (MIC).

Figure 6 differs from the arrangement shown in Figure 4 in that the noise signals are converted into binary signals, by the zero-crossing detectors (ZCD), before being combined.

Fig. 7 shows a specific example of the system of Fig. 6 where the combiner (MIC) is formed by a plurality of suitably connected Exclusive-OR logic gates (XOR).

Figure 7 represents a preferred embodiment of the invention, assuming that the number of noise sources is equal to four. In one particular example of this embodiment, assume that the rms bandwidth measured in Hertz (i.e., $B_s/2\pi$) of the output of each noise source (PNS) is equal to 25 MHz. For the purpose of this analysis it is also assumed that zero-crossing detectors and Exclusive-OR gates have infinitely fast responses. The half-height width of the correlation function of a binary waveform obtained at the output of any of the zero-crossing detectors is equal to 10.6 ns. However, the half-height width of the correlation function of the resulting binary waveform obtained at the output of the system is equal to 3.2 ns.

Fig. 8 shows the shape of the correlation function of a random binary waveform generated by such a system.

Fig. 9 shows yet another system according to the present invention that comprises a single physical noise source (PNS) followed by a spectrum-shaping filter (SSF) and a zero-crossing detector (ZCD), a plurality of binary delay lines (BDL) and a suitable multi-input-single-output combiner (MIC) that processes the waveforms in such a manner that their respective zero crossings are, at least partly, preserved. A random binary waveform (RBM) is obtained at the output of a combiner (MIC).

This is thus similar to the embodiment of Figure 6, except (analogously to Figure 5) the separate noise sources are replaced by delay lines.

Fig. 10 shows a specific example of the system shown in Fig. 9 where the combiner (MIC) is formed by a plurality of suitably connected Exclusive-OR logic gates (XOR).

Some, but preferably not all, of the physical noise sources (PNS) referred to above may be replaced by other, deterministic sources utilized to generate periodic or aperiodic non-random signals.

Fig. 11 is a functional block diagram of another random binary waveform generator representing another preferred embodiment of the present invention. The system consists of four channels; each of three identical channels comprises a wideband physical noise source (PNS), a spectrum-shaping filter (SSF) and a zero-crossing detector (ZCD).

The fourth channel comprises a pseudorandom binary sequence generator (PRBS) driven by a clock unit (CLK) whose frequency may be constant or may vary. Preferably the pseudorandom binary sequence generator (PRBS) is a shift register with a feedback circuit constructed in accordance with the prior art. A random binary waveform is obtained at the output of the last gate (XOR) of the cascade. Although the correlation function of a pseudorandom binary sequence is periodic, the correlation function of the resulting random binary waveform is aperiodic.

In one example of the arrangement of Figure 11, assume that the rms bandwidth measured in Hertz (i.e., $B_s/2\pi$) is equal to 15 MHz. For the purpose

of this analysis it is assumed that zero-crossing detectors and Exclusive-OR gates have infinitely fast responses. It is also assumed that the pseudorandom binary sequence generator (PRBS) is driven by a clock with frequency of 66 MHz. The pseudorandom binary sequence generator (PRBS) consists of seven stages with a suitable feedback to obtain a sequence of length 127. The half-height width of the correlation function of a binary waveform obtained at the output of any of the zero-crossing detectors is equal to 17.6 ns. However, the half-height width of the correlation function of the resulting binary waveform obtained at the output of the system is equal to 5.2 ns.

Fig. 12 shows the shape of the correlation function of a random binary waveform generated by the above system incorporating the present invention.

The invention thus provides a way of obtaining a random binary waveform with a sharp correlation function. This is achieved in the preferred embodiments by generating Gaussian signals and combining them in a non-linear manner in order obtain a non-Gaussian signal which is used to produce the random binary waveform. Various modifications are possible. For example, it is possible to use exclusively deterministic pseudo-random signal sources, although this is not preferred. If such an arrangement is used, for example using a plurality of shift register arrangements, it is preferred that the shift registers be clocked by non-synchronous, and preferably non-correlated, signals.

A random binary waveform generator in accordance with the present invention is particularly suited for use in a time delay determination system according to UK Patent Application No. 9828693.3, the contents of which are incorporated herein by reference.

CLAIMS:

1. A method of generating a resultant signal containing events which occur at random intervals, the method comprising generating a plurality of preliminary signals each containing events occurring at random intervals and combining the preliminary signals in such a way as to intersperse the events.

2. A method as claimed in claim 1, wherein each preliminary signal is an analog signal, and the resultant signal is a binary signal.

3. A method as claimed in claim 2, wherein the analog signals are combined, and the combination is then converted to a binary signal.

4. A method as claimed in claim 3, wherein the analog signals are combined by analog multiplication.

5. A method as claimed in claim 2, wherein the analog signals are converted into binary signals, and the binary signals are combined in order to produce the resultant signal.

6. A method as claimed in claim 5, wherein the binary signals are combined by an XOR operation.

7. A method as claimed in any preceding claim, wherein at least one of the preliminary signals is a non-deterministic signal.

8. A method as claimed in any preceding claim, wherein at least one of the preliminary signals is a chaotic signal.

9. A method as claimed in any preceding claim, wherein at least one of the preliminary signals is a time-delayed version of another of the preliminary signals.

10. A method as claimed in claim 9, wherein the time delay has a value such that the correlation function of said one preliminary signal for that value is substantially zero.

11. A method as claimed in any preceding claim, including producing a signal from a noise source and applying a spectral filter to the signal in order to obtain a said preliminary signal.

12. A method as claimed in any preceding claim, wherein the number of preliminary signals is equal to 3 or 4.

13. A method of generating a random signal, the method being substantially as herein described with reference to any of Figures 4 to 10 and 12 of the accompanying drawings.

14. A method of detecting objects comprising measuring the delay between transmission of a resultant signal generated by a method according to any preceding claim and receipt of the reflection of the signal from the object.

15. Apparatus arranged to generate a signal containing events which occur at random intervals using a method as claimed in any one of claims 1 to 13.

16. Apparatus for generating a random signal, the apparatus being substantially as herein described with reference to the accompanying claims.

ABSTRACT

A random binary signal is generated using a plurality of noise sources, each of which defines events occurring at random intervals,the outputs of the sources being combined in such a way that the events are interspersed in the resultant signal.

[Fig. 4 to accompany the abstract]

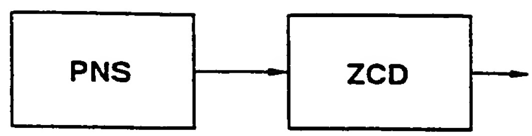

FIG. 1

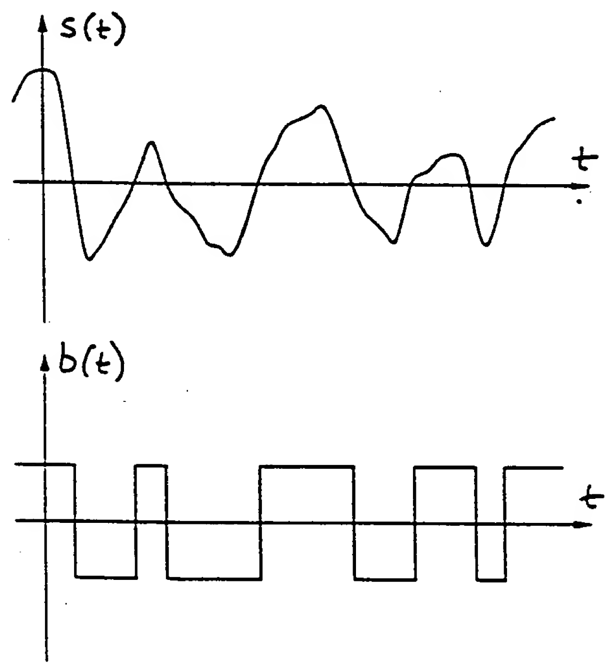

FIG. 2

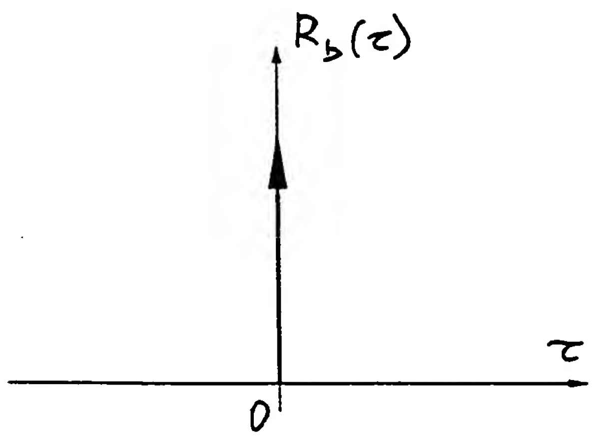

FIG. 3

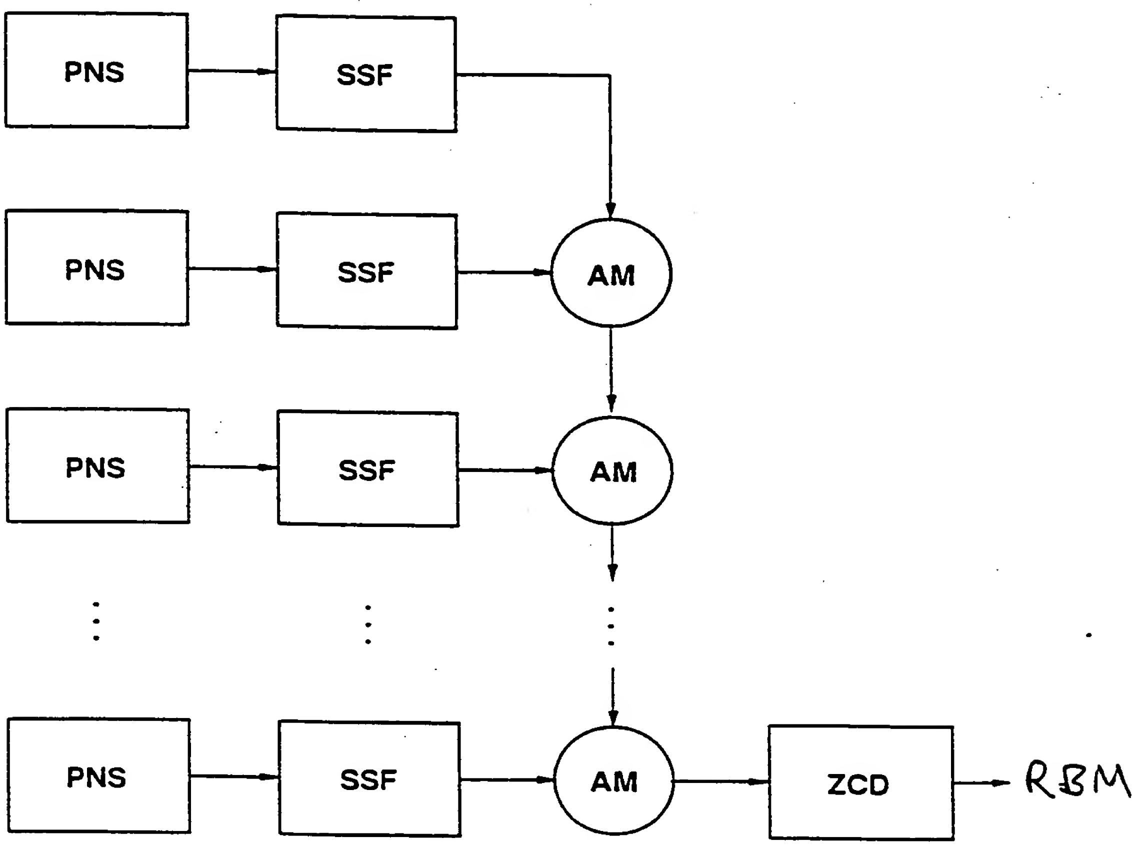

FIG. 4

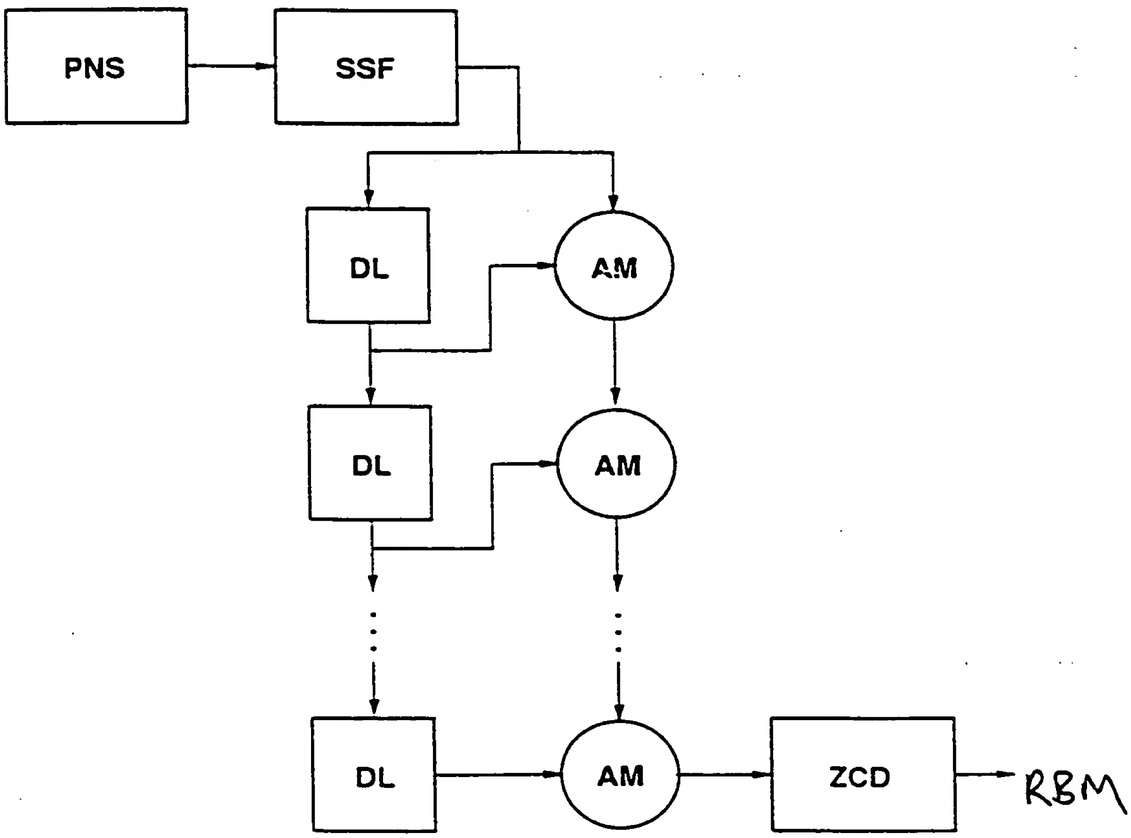

FIG. 5

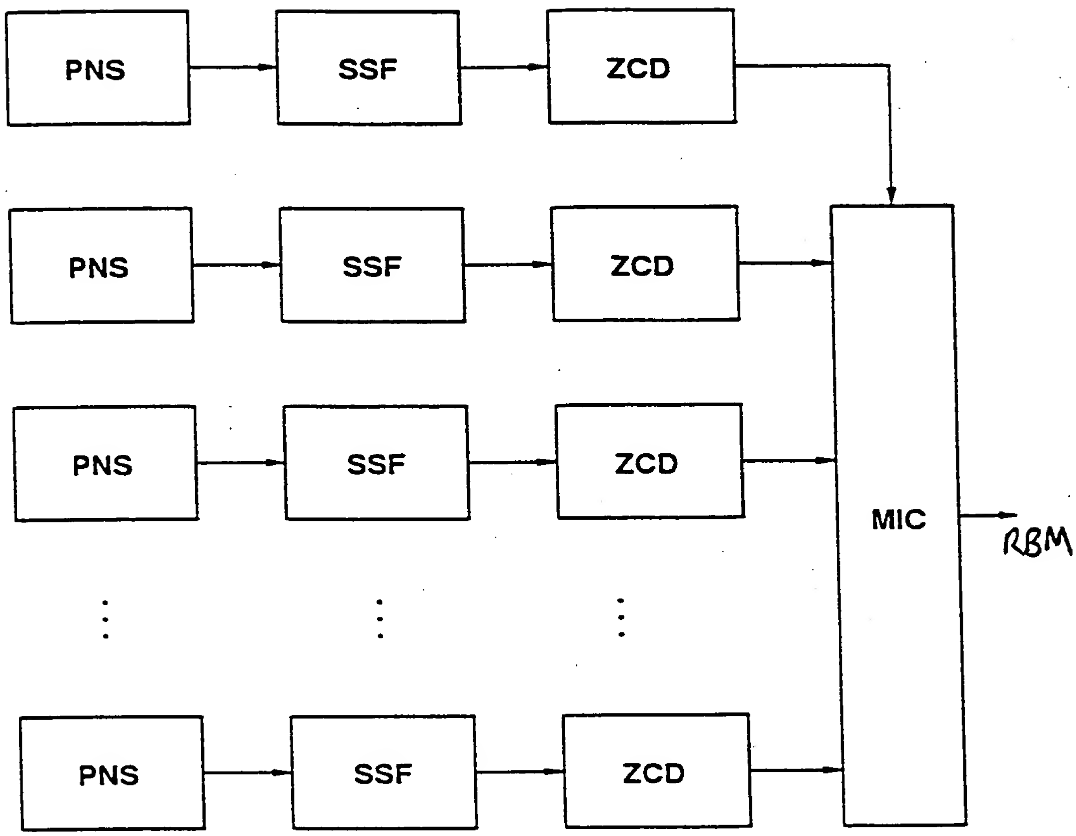

FIG. 6

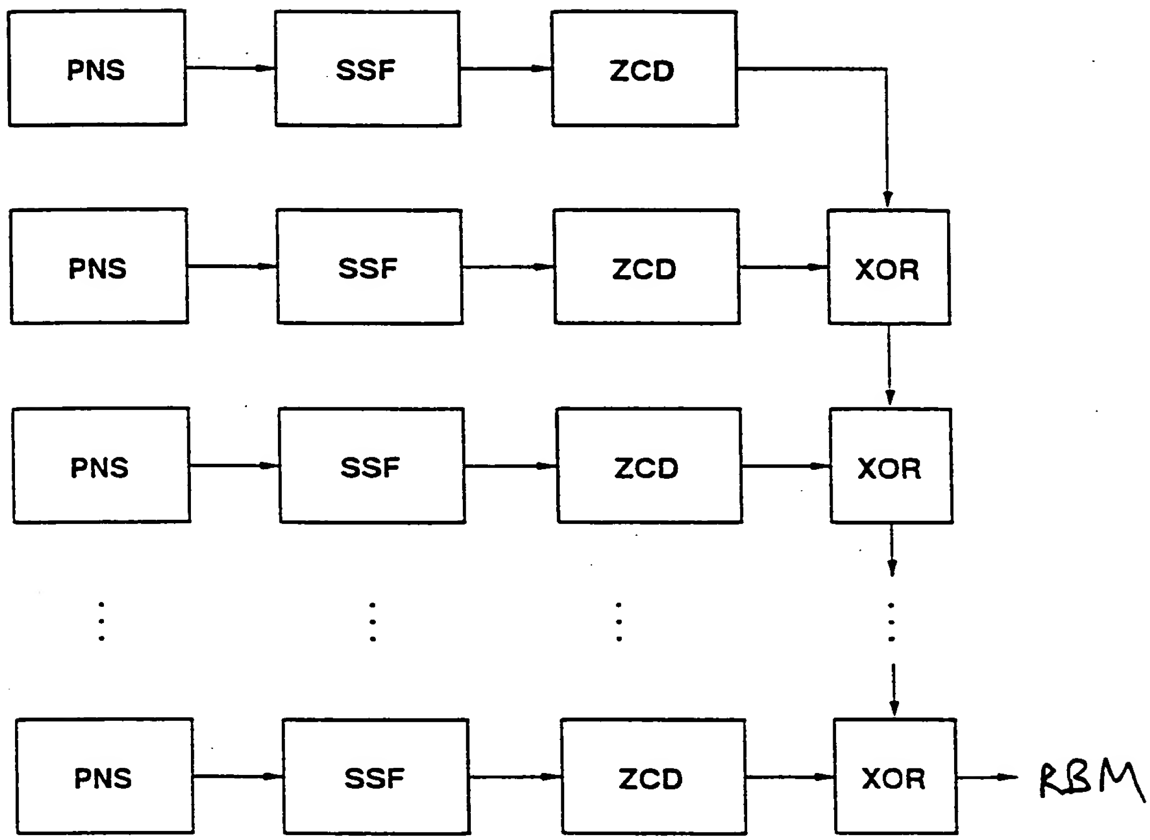

FIG. 7

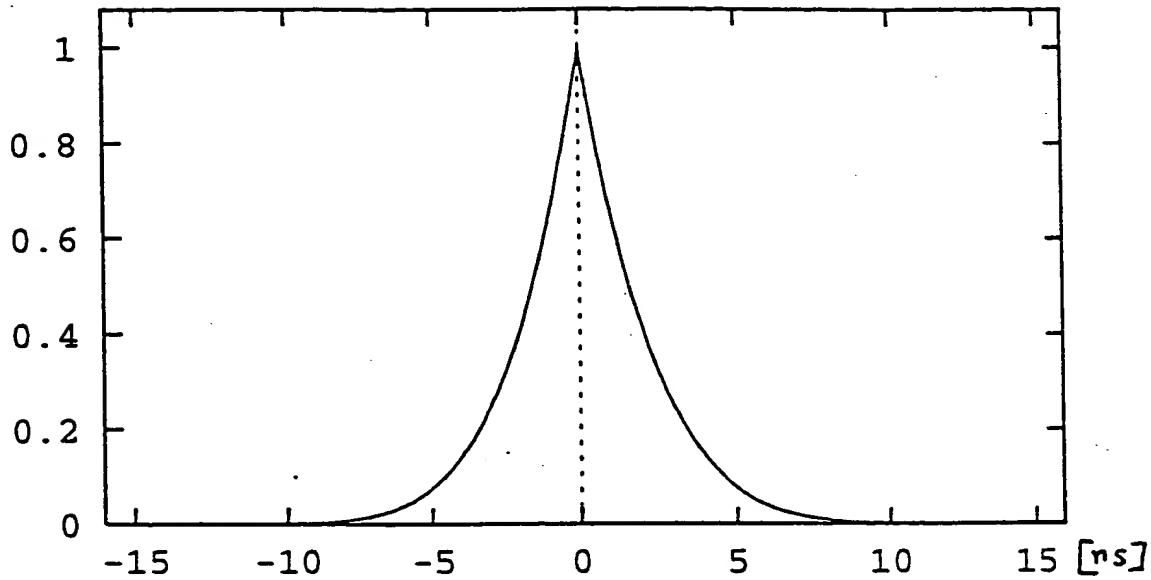

FIG. 8

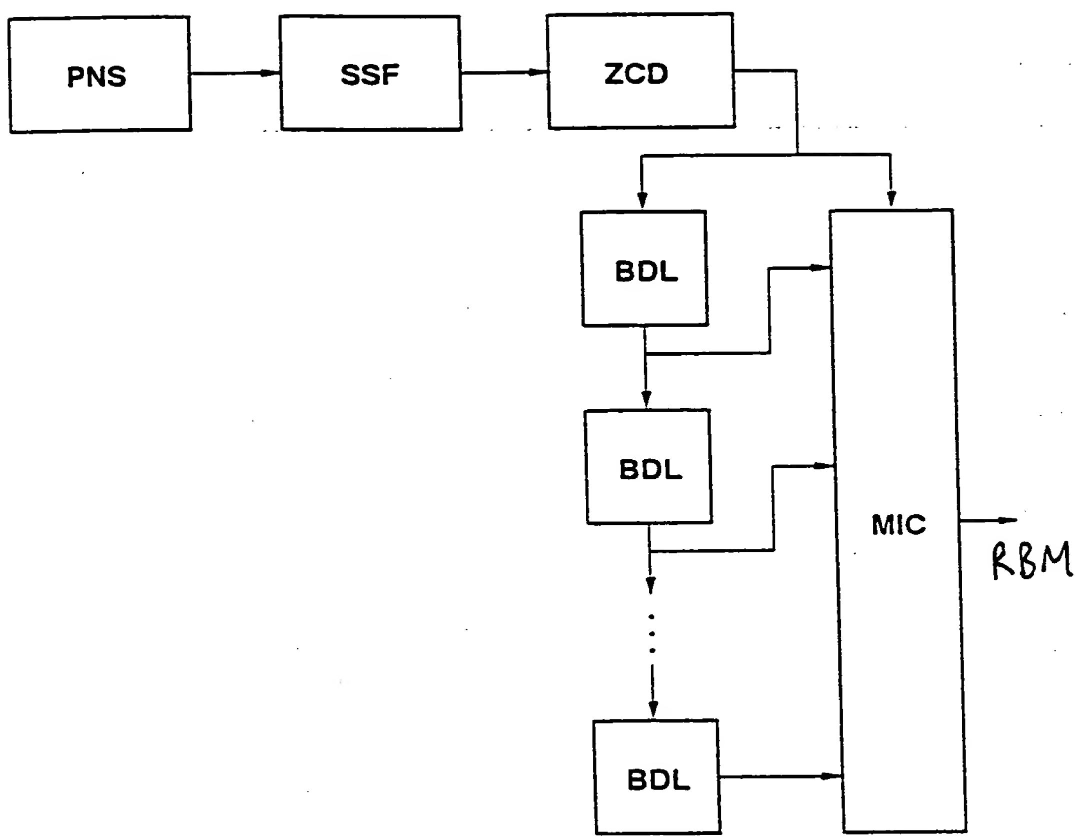

FIG. 9

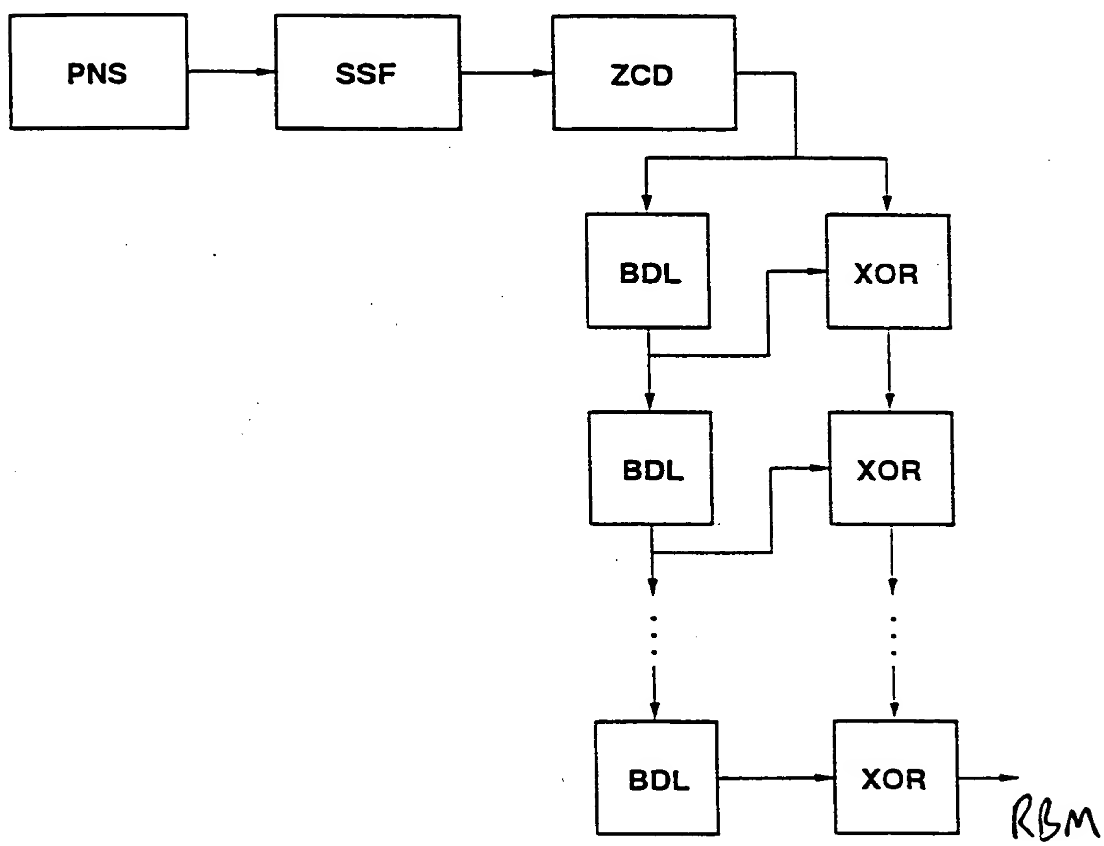

FIG. 10

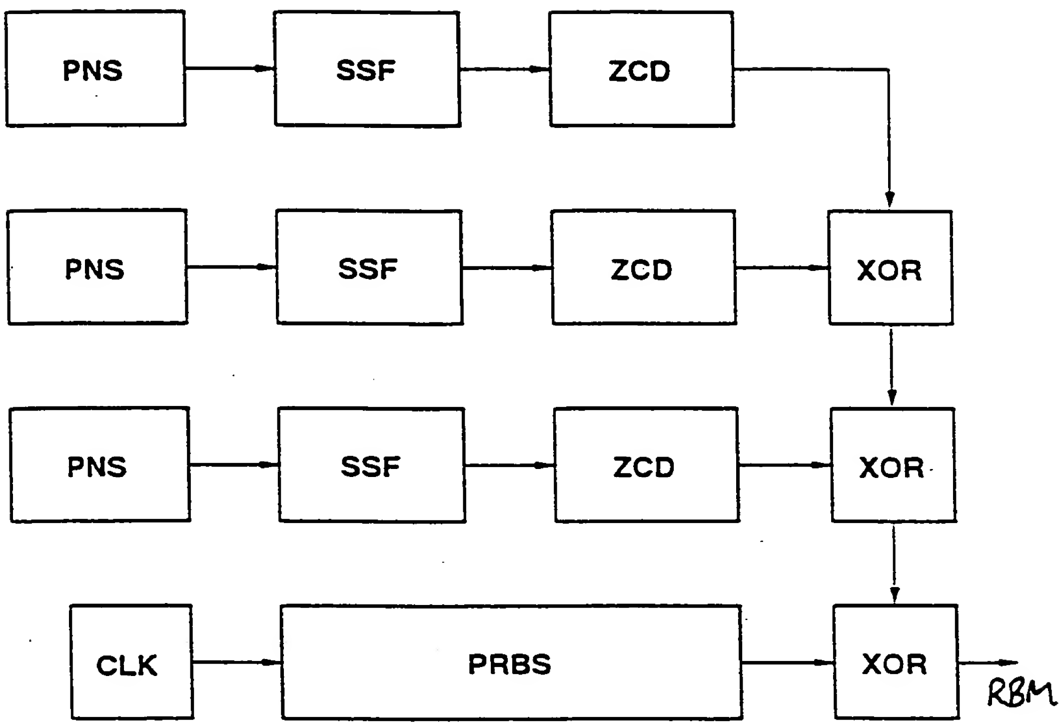

FIG. 11

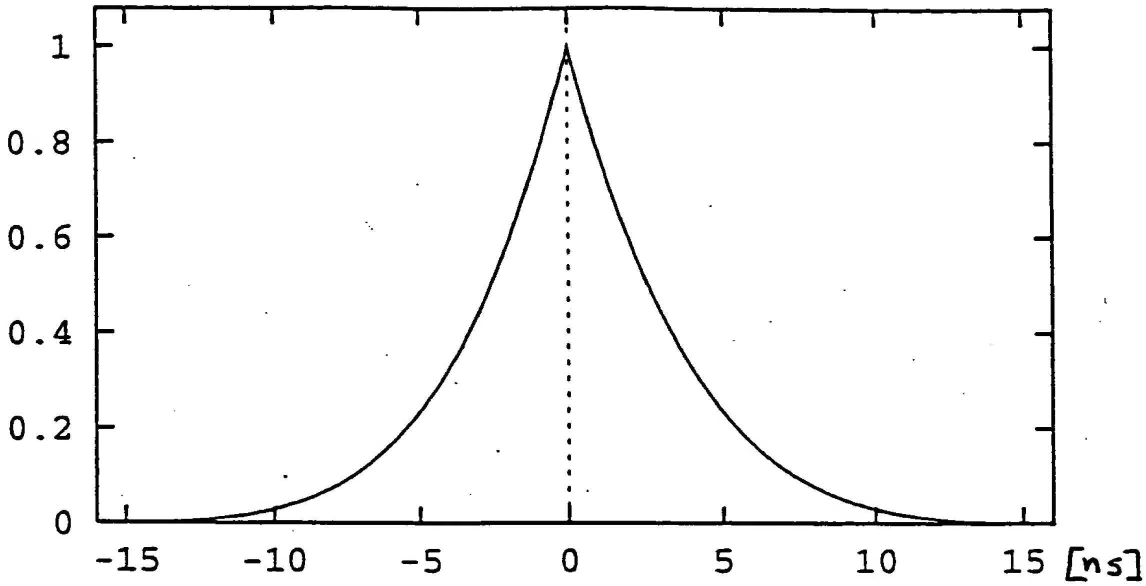

FIG. 12